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As research vehicle altitude and speeds have increased, it has become necessary to develop new techniques to measure the characteristics of the ambient atmosphere. The value of the various atmospheric characteristics may be required for either scientific or engineering purposes. In either case the problems encountered in attempting to obtain accurate data are often the same. I would like to discuss the work that is being done at the Langley Research Center where we are investigating the feasibility of utilizing gamma ray scattering as a technique for air-density measurement. The work to be described has been performed in an attempt to satisfy the design goals that are outlined in figure 1.

The first four of these goals are probably common to all instrumentation placed aboard aircraft and rockets. Generally everything must be lightweight, compact and rugged, and must have small power consumption. The remaining goals are more specialized, however. Since it was necessary to measure the atmospheric density during the period when reentry heating would be significant, we felt that a reasonably accurate measurement to an altitude of 90 km would be required. Because reentry vehicles are usually protected from the extreme heat by an ablation material it is not possible to allow the use of orifices or special windows in the vehicle skin. Similarly it would be necessary that the selected technique be unaffected by the presence of shock waves or a plasma.

After consideration of the design goals, we decided that the volume of air whose actual characteristics were measured would be located outside the vehicle flow field. This indicated that some form of radiated energy would be utilized. After investigation of both particle and electromagnetic radiation it was decided that a gamma ray scattering technique would have the greatest probability of satisfying the design goals. Previous work in the area of gamma ray scattering had shown that an appreciable number of low-energy gamma rays would be air scattered at large scattering angles.

In principle at least the technique seemed rather simple. A gamma ray emitting source and a detector, separated by a suitable shield, would be flown in the payload. The geometry would be arranged such that the detector would count only those photons that had been scattered by the air at some predetermined distance from the vehicle. This count rate, which would be related to the air density, would then be telemetered. Although it would not be possible to separate the counts caused by the scattered photons from the counts caused by the ambient X-ray background, we felt that this would be a minor problem since the literature indicated that the ambient radiation level would be low.

After a limited analytical study of the scattering for a geometry that was realistic for a flight payload, a test unit was built and tested in a

60-foot-diameter spherical vacuum chamber. The results of this test confirmed the theoretically predicted linear relationship between count rate and density and yielded the scattering scale factors that were required for the design of a flight payload.

Figure 2 shows a sketch of the layout of the flight payload. A 24 Curie Cerium 144 radioactive source was located in the nose tip. Although the predominant radiation emitted by this source is of low energy, a daughter of the Cerium emits sufficient radiation at 2 Mev to require the use of a lead shield 15 inches thick between the source and the detector. The detector was a sodium iodide scintillation crystal coupled to a photomultiplier tube. The output pulses were then amplified and shaped. The counting rate was reduced to a level compatible with the FM-FM telemetry system by means of a series of binary flip-flops. The transmitted pulses were tape recorded at the telemetry receiving station for later counting by a ground-based electronic counter. This payload, which weighed approximately 125 pounds, was launched to a peak altitude of 127 km by a Nike Apache rocket from Wallops Island, Virginia.

Prior to the flight test the payload was calibrated in the 60-foot-diameter vacuum sphere. Because of the difficulty of safely handling a 25 Curie radioactive source, the payload was calibrated using an 0.394 Curie source of the same geometry as the flight source. The results of this calibration are shown in figure 3. The count rate varied approximately linearly with density at the higher density levels, then approached a constant value as the air density became low. This constant value of counting rate was attributed to the combined effects of ambient radiation, direct transmission through the lead shield, and scattering from the steel walls of the chamber. For the linear portion of the curve the scale factor was found to be 58.47×10^5 pulses per second/slug/ft^3/Curie.

Three Arcas rockets - one having a temperature sensing payload and two having Robin balloon density sensing payloads - and two radar tracked radiosonde balloons were flown in support of the firing. Since the data from these supporting tests agreed with the 1962 U.S. Standard Atmosphere within the estimated accuracy of the measurements, the Standard Atmosphere will be used as a standard of comparison in the following figures.

Figure 4 shows the telemetered count rate as a function of the vehicle altitude. Although the counting rate was approximately as expected and fell exponentially, it soon approached a value of 440 pulses per second. This count rate was maintained with only minor variation over the entire portion of the flight that is above 50 kilometers. This 440-pps count rate was considerably higher than had been expected. Calculations had indicated that the count rate near apogee would be approximately 30 pulses per second (25 pps for background and 5 pps for direct transmission through the lead).

When the average count rate for the period above 50 km is subtracted from the data of figure 4, one obtains the data shown in figure 5. As indicated, the circles represent the measured count rate, while the solid line represents the density of the U.S. Standard Atmosphere. As can be seen, the agreement between the two was rather close. Unfortunately, however, because of the higher than expected constant counting rate the data were not meaningful over

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as large an altitude interval as had been expected. The data indicated that the sphere calibration was valid and that the payload was measuring the density of the free stream outside the vehicle bow shockwave.

After completion of the data analysis we decided that the technique still appeared promising, but that certain areas required further investigation before operational hardware based on this concept could be designed. Of most importance is a determination of the source of the large residual count rate at essentially zero ambient density. During this same time period some interest was expressed in utilizing the technique to measure the density of the atmospheres of other planets. In view of the questions raised by the flight test and the interest in applying the technique elsewhere the work outlined in figure 6 is presently being pursued.

It is planned that two flight tests of a generally similar payload will be conducted later this year. In these tests the payload will contain a source of higher effective source strength and a mechanism that is designed to alternately cover and uncover the source. It is hoped that in these tests the measurement will be extended to higher altitudes and that a better estimate of ambient background will be obtained.

Items two and three are being investigated by means of a much more sophisticated theoretical treatment of the scattering process. For this investigation a mathematical model of the scattering process has been developed. This model will allow (via a digital computer) the investigation of such items as atmospheric composition variation, multiple scattering in the rocket skin, and direct transmission of the radiation through the shielding.

As was probably noticed the weight of this payload was rather high. So far as the actual sensor is concerned, the major contributors to the weight problem are the shielding and the detector. If an economical source, that does not emit at high energies, were available, the shielding weight could be reduced considerably (possibly to a pound or less). When solid-state detectors have been developed to reasonable efficiencies, the detector size and weight can be reduced drastically.

As shown in this flight test, very high source strengths will be required if measurements are to be made to altitudes of 90 km in the earth's atmosphere. Although a radioactive source is an extremely reliable and compact device requiring no power input, the problems involved in the licensing and handling of strong sources limit its usefulness. As a result, the feasibility of utilizing an X-ray tube as a source is being investigated.

A rocket payload has been flown to investigate the feasibility of utilizing gamma ray scattering for measuring atmospheric density. The results have indicated that a density measurement can be made without compromising the structure of the vehicle, and that it is possible to calibrate the payload in a vacuum sphere using a source of reduced intensity. If one is limited to relatively low cost sources, however, the measurement is limited by rather high sensor weights. Hopefully the availability of different sources and the development of new detectors will allow a large reduction in payload weight. As a result of the limitations introduced by the radioactive source, an investigation to determine the feasibility of utilizing an X-ray tube as a source is being conducted.

1. LIGHT WEIGHT
2. LOW POWER CONSUMPTION
3. SMALL VOLUME
4. RUGGED (SUITABLE FOR ROCKET ENVIRONMENT)
5. ABLE TO OPERATE TO ALTITUDES OF 90 KM
6. UNAFFECTED BY PLASMA SURROUNDING VEHICLE
7. NO ORIFICES OR WINDOWS THROUGH SKIN

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Figure 1.- Design goals for an air density sensor.

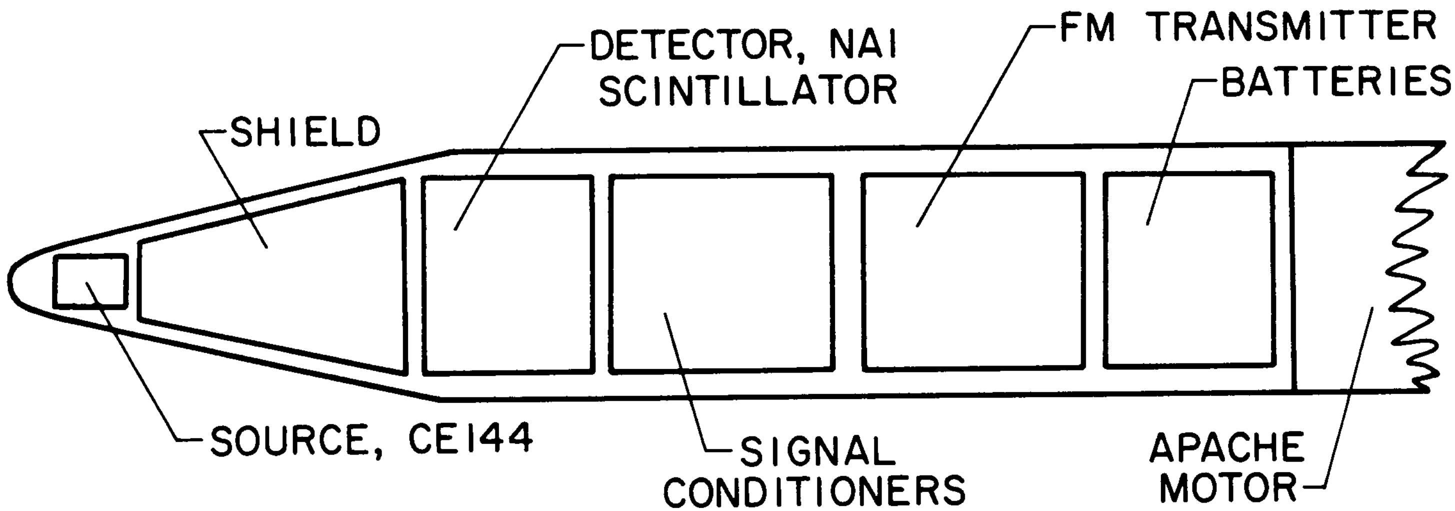

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Figure 2.- Flight payload schematic.

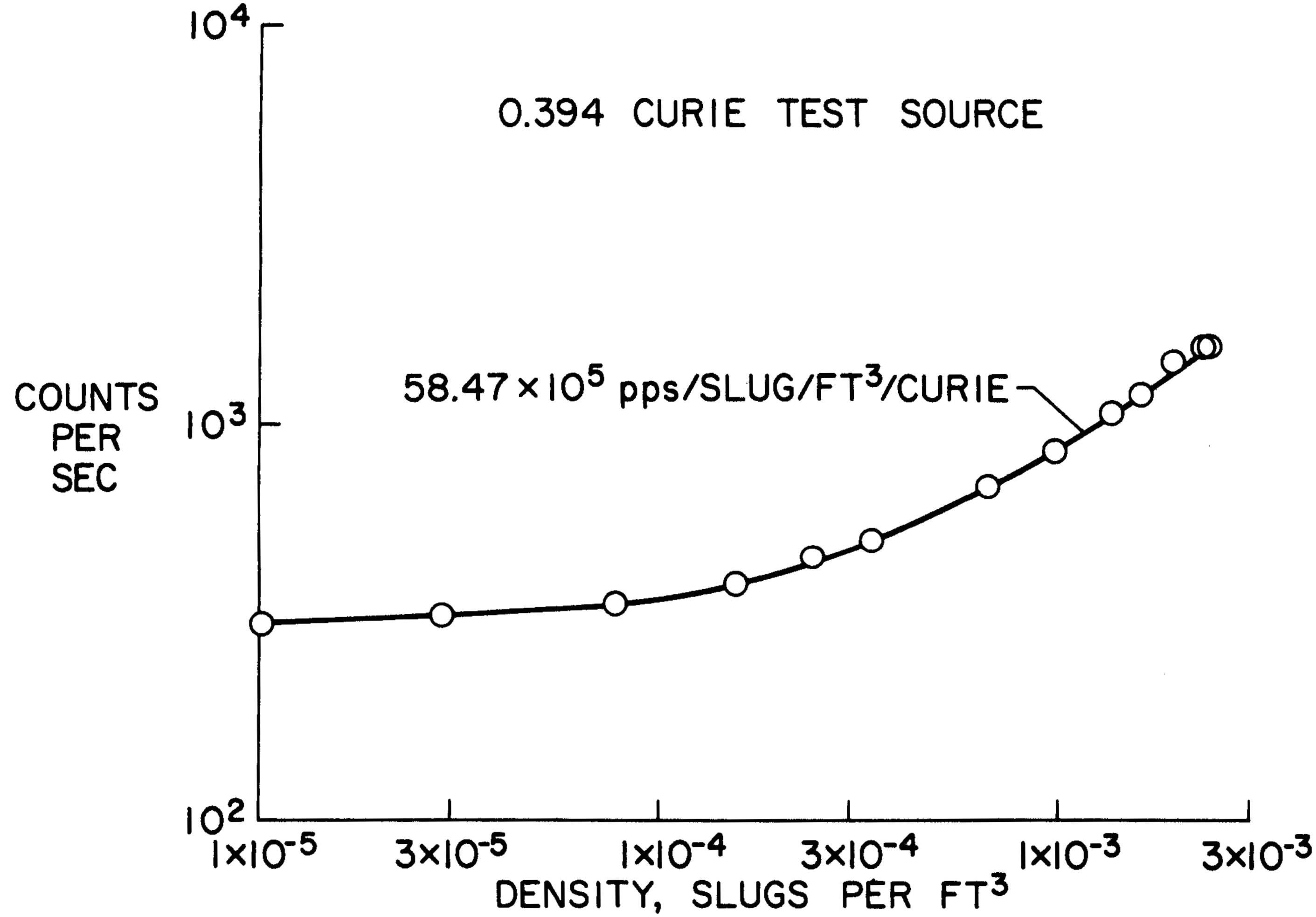

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Figure 3.- Vacuum chamber calibration.

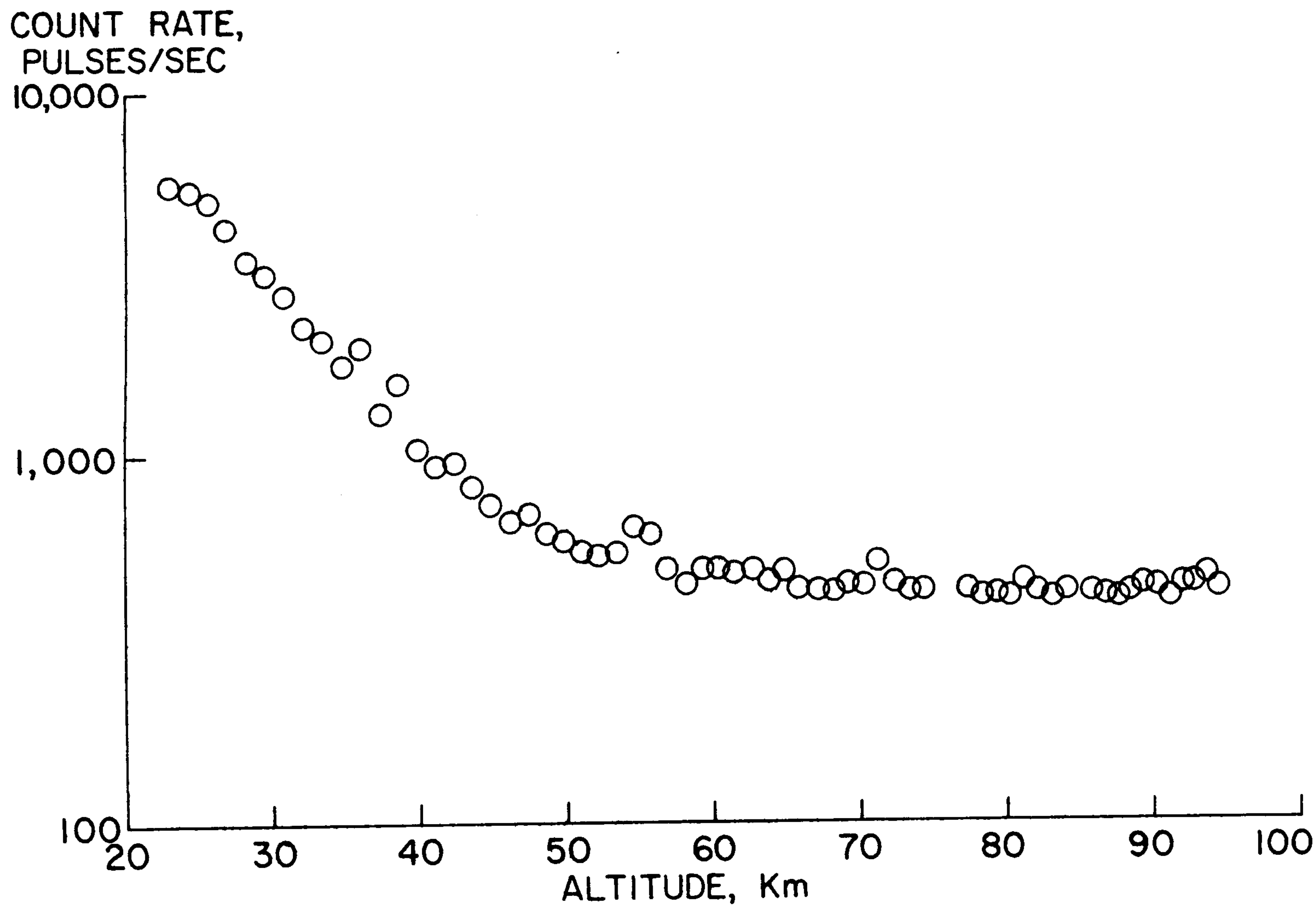

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Figure 4.- Flight data.

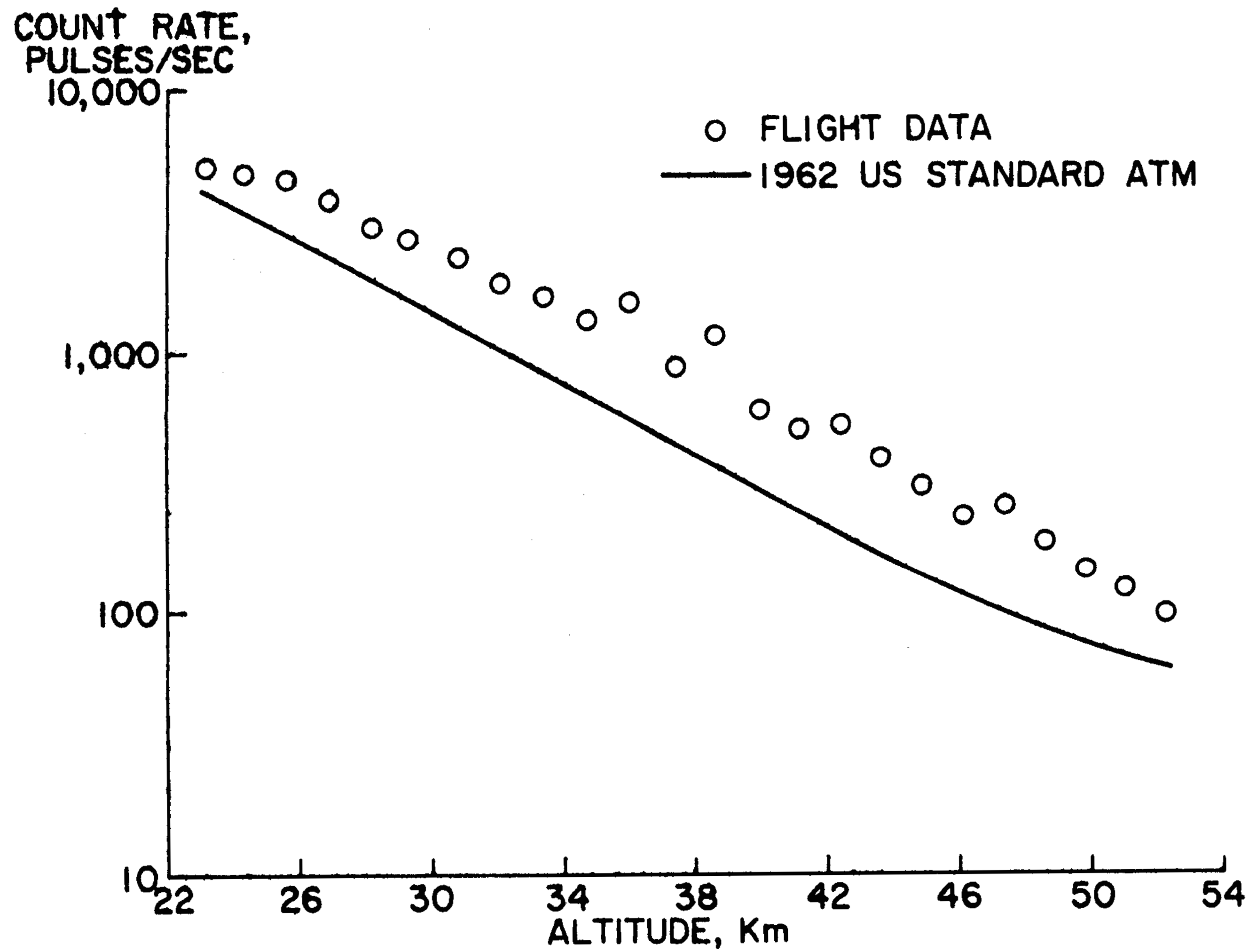

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Figure 5.- Flight data, background subtracted.

1. FURTHER FLIGHT TESTS
2. DETERMINATION OF SOURCE OF HIGH STEADY STATE COUNT RATE
3. DETERMINATION OF COMPOSITION EFFECTS
4. INVESTIGATION OF TECHNIQUES FOR REDUCING PAYLOAD SIZE AND WEIGHT
5. INVESTIGATION OF X-RAY TUBE SOURCE

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Figure 6.- Present work and future development.

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